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# Longitudinal Water Temperature Changes in Selected Black Hills Streams during a Period of Drought


**South Dakota**
**Department of**
**Game, Fish and Parks**
Wildlife Division
Joe Foss Building
Pierre, South Dakota 57501-3182



**Completion Report**
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# Longitudinal Water Temperature Changes in Selected Black Hills Streams during a Period of Drought

By

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South Dakota Department of Game, Fish and Parks.

Completion Report

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# PREFACE

The data and summaries presented in this report were collected in 2005. Copies of this report and references to the data can be made with permission from the author or the Director of the Division of Wildlife, South Dakota Department of Game, Fish and Parks, 523 E. Capitol, Pierre, South Dakota, 57501-3182.

The author would like to acknowledge the following individuals who assisted with the data collection, data entry, and editing this manuscript from the South Dakota Department of Game, Fish and Parks; Will Sayler and Keith Wintersteen for reviewing this document and Ron Tietsort and other Custer State Park staff for rescuing missing temperature monitors from the public.

The collection of data for these surveys was funded, in part, by Federal Aid in Sport Fish Restoration, (D-J) project F-21-R, "Statewide Fish Management Surveys." Some of these data have been presented in previous annual reports.

## EXECUTIVE SUMMARY


Streams in the Black Hills are poorly known in regard to the extremes of temperatures that they exhibit. This study was designed to determine the extent of temperature change seen in four of the area streams during a period of drought. A secondary objective was to determine the extent of temperature increase as these streams flowed downstream. The Black Hills under drought conditions are perhaps showing a worse case scenario, in regards to high temperatures, for many of the area streams as there were little or reduced runoff events to alleviate extreme temperatures.

The State of South Dakota has established two criteria for coldwater fisheries. The two levels are designated for permanent coldwater fish production and marginal coldwater fish production. Each of these levels is based on a single maximum temperature reading. In many instances, the temperatures realized in these waters exceeded the states' water quality designation. However, the presence of trout in these waters indicates that perhaps there are certain conflicts with the designated use and the presence and thus survival of wild trout.

Two events alleviated potential detrimental effects on one of the fisheries (Rapid Creek). The coldwater releases from Pactola Reservoir provided a refuge for trout survival during the hotter periods of the summer. Higher water outflows from Pactola Reservoir, due to municipal and agricultural downstream demands, allowed for further cooling events during high summer temperatures. Cleghorn Springs had an additional buffering effect for Rapid Creek.

Spearfish Creek appeared to suffer little in regards to extreme temperatures. Throughout the entire sampling reach, temperatures showed a maximum variation of six degrees Celsius. Water temperatures at the lower portions of Spearfish Creek are approaching levels where trout show signs of stress in the laboratory.

Whitewood Creek produced the highest water temperatures of any of the four sampled streams. Attempts were directed to determine the extent of influence that the discharge of water from the town of Deadwood's wastewater treatment facility had on the streams water temperature. At least at the scale used in this report the extent appears to be limited. Excessive temperatures in the lower areas of the sampled stretch of Whitewood Creek are at levels that likely prohibit long-term survival of trout or other coldwater fish species.

Grace Coolidge Creek was the fourth stream sampled. Flows from Center Lake, overhead stream cover and possibly additional contributions from associated springs allowed for moderate temperatures. Pond temperatures were elevated, but not to the extent that earlier stocked trout would not have survived.

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## INTRODUCTION

Water temperature and how it changes as it travels along a stream course can have a significant impact on biological systems. Water normally starts in the upper reaches of a watershed via snowmelt or alluvial spring and precedes down an elevation change. If no other addition occurs, (i.e. other snowmelt or coldwater spring) then the water should be expected to increase in temperature as it travels downstream towards lower elevations and subsequent warmer temperatures. In many Black Hills streams, occasional springs provide for a dynamic situation in regards to water temperature. Where normal increases in water temperatures are likely to correlate with an increase in sunlight as the stream migrates downstream, the influences of localized springs may help to offset this occurrence. Directly influenced by these temperature changes are the biotic component including the fish population.

The interaction of temperature and fish has been studied in many aspects including egg maturation, onset of gonad maturation and feeding mechanisms (Fry 1967, 1971, Hutchinson 1976 Beitinger and Fitzpatrick 1979). Short-term influences have equal importance in the overall stress and survival of many species of trout. This study was implemented to determine the water temperatures in several important streams and the impact that a drought has on water temperatures longitudinally during a period of drought. While not directly looking at the various impacts the water temperature may be having on fish populations, certain speculative ideas may be expressed via the data collected and the potential effects that may be expressed on the aquatic populations.

Temperature and the variance during the normal yearly cycle have a profound impact on the overall makeup of the fish community. Interruption of spawning, a reduced adult and juvenile survivorship and altered resource utilization all have been shown to have been correlated to temperature changes at inopportune times (Winn 1958, Schlosser 1985, Scholsser and Toth, 1984, Lotrich, 1973 and others). In combination, these effects may influence age structures of the fish represented in the stream community, especially of smaller sized fishes (Walsh and Burr 1985).

Drought may have a significant impact on the fish community as certain guilds of fish have specific temperature preferences. Trout, normally classified as a coldwater fish, require water of good quality, including a temperature range not exceeding 22$^{o}$C (Elliott 1981). The extent that temperatures remain under thermal thresholds dictates a species range. Under unusually dry conditions, fish may be more often exposed to extreme temperatures due to the reduction of cold spring water contributions and the buffering of these cooler water temperatures.

Starting in the 1970’s, discussion concerning water temperatures and development of teleost tolerance to temperatures became a topic of interest. Many of these original studies involve the temperature thresholds that fish species were able to withstand and demonstrated the physiological and behavioral adjustments that many North American coldwater fish have or utilize in order to survive extreme temperatures (Elliott 1976, Wurtsbaugh and Davis

1977). Further discussion on temperature influences and a historical background on their influences for Black Hills waters can be found in Simpson 2006.

## INFLUENCES OF RESERVOIRS IN A RIVER SYSTEM

Streams as a system continue along their course with external influences that affect their physical properties. Groundwater, in the form of springs, contributes not only volume of the water but also may influence the temperature as well. Warming of the water is primarily derived from radiant and air temperatures. Localized longitudinal streamside vegetation has an impact on stream temperature. If vegetation is limited then radiant heat is absorbed into the water with an associated increase in temperature. As a stream course increases in width, sunlight can have greater influence in concentrating energy for a given amount of surface area.

Water temperature can be influenced by physical parameters along the stream. Under "normal" conditions, a meandering stream develops certain characteristics. Streamside vegetation and undercut banks are two such characteristics that have an immediate impact on water temperatures. The impact of shade contributes to reduce or limit the immediate temperature. Each of these factors also provides a measure of protection for fish species in regards to avian predators and may even fulfill resting requirements for individuals.

As the stream travels downwards, the number, size, and depth of pools or ponds will influence temperature. The restricted movement of water allows for not only an increase in sedentary volume of water and thus more area open to sunlight energy but also allows for warming of sediments, which impacts water temperature as well.

Trout, as a physiological grouping, require water with high oxygen content (Hynes 1970). For trout species, the rate of metabolism rises very rapidly with increasing temperature (Graham 1949). In part of Grahams' (1949) study, he found that brook trout (*Salvelinus fontinalis*) experienced an oxygen uptake that was dependent not only on water temperature but included the associated saturation of oxygen in the water. Oxygen being less soluble in warmer waters than in colder water and the fact that oxygen demands of the fish also increase leads to stress when trout are exposed to increased temperatures. It is for these reasons that any conditions which even slightly decrease oxygen concentrations during warm weather may have deleterious effects for trout species.

## TROUT MANAGEMENT IN THE BLACK HILLS

William Ludlow, the chief engineer of the scientific corp in the first exploration of the Black Hills led by Lt. Colonel George A. Custer, noted “a small chub and sucker perhaps a pound in weight” in the first report of ichthyofauna in the Black Hills. Later scientific studies were to show a somewhat limited fish composition compared to other parts of the country. The absence of glaciation stream capture events and a continental climate characterized by low precipitation amounts, hot summers, cold winters and extremes in precipitation probably contributed to the absence of native salmonids despite adequate water quality parameters to the Black Hills region. It would take until 1886 for the first presence of trout in the Black Hills when two entrepreneurs transported brook trout from Colorado. Soon federal and later state trout hatcheries were established in the Black Hills areas to provide a source of food and recreation to residents and promote tourism.

From a hydraulic standpoint, the Black Hills are important for the recharging of area bedrock aquifers (Carter et al, 2002). Two primary aquifers, the Madison and Minnelusa, are linked to the surface-water resources. In the Black Hills, ground water flows radially away from the central core. The numerous headwater springs occur in limestone formations and contribute coldwater of high quality. Groundwater then flows over igneous and metamorphic rock until it reaches several loss zones. These areas include collapse and solution features, such as sinkholes and caves, and are responsible for the Madison aquifer’s ability to accept large amounts of recharge. The Minnelusa formation also receives recharge within the outcrop of its formation (Carter et al 2003).

This study was an attempt to verify the extreme temperatures that trout and other fish species experience during periods of extended drought in the Black Hills of South Dakota. Many areas of the Black Hills were under drought conditions for up to five years before the installation of these temperature recorders. By placing these recorders in waters where known salmonid populations were thriving, or at minimum surviving, during a drought period we will have better knowledge on their capacity to withstand long-term below normal water flow conditions.

When water temperature exceeds the $22^{o}$ C, most literature suggests that reduction in food intake occurs and thus decreased growth and reproduction are the result. In cases where water temperature exceeds $24^{o}$ C, then some mortality of individuals is likely to occur. These guideline temperatures certainly play a part in the distribution of wild trout populations. In cases where water temperatures are elevated, then stocking of trout also becomes an issue. Simpson (2006) suggested various times when it was appropriate to stock different waters based on water temperature. Failure to follow specific guidelines during stocking of trout can lead to reduced public perception involving the survival of the stocked product. Public agencies can little afford the poor public opinion resulting from a die-off of recently stocked fish when it can be prevented.

# SAMPLING METHODS

## STUDY AREA

Four watersheds were sampled during this study. In each of these watersheds, only the major stream was used as a source of temperature data. The specific stream reaches were developed based on their locations (northern Black Hills, central Black Hills and southern Black Hills). Additional aspects were to assess the impact certain physical factors or features have on stream temperature. One example of this was the impact of Pactola Reservoir on the stream temperature by measuring temperature above and below this large reservoir.

Rapid Creek is the major stream in the Rapid Creek watershed in the central Black Hills. It is supplied by springs, runoff and reservoir releases. All of this water flows into Pactola Reservoir and then flows towards Rapid City. During the summer, irrigation and municipal water demands increase the water flows below Pactola and with these flows resulting in a reduction in water temperature due to the hypolimnion release. Several springs exist in the watershed, but the major spring influence in Rapid Creek is from Cleghorn Springs. Just below Cleghorn Springs the creek flows into a moderate sized lake (Canyon Lake). In each of these physical alterations (Pactola Reservoir, Cleghorn Springs, and Canyon Lake) the impact of these were determined.

Spearfish Creek was one of two major streams sampled during this period in the northern Black Hills. Spearfish Creek is a free flowing stream for much of its length (with the exception of small weirs) until it reaches a geological feature called the loss zone. The loss zone is an area of limestone rock that is permeable to water and much of the water in the creek is thus lost to absorption into local aquifers. Water has been taken above the loss zone for mining and municipal uses since pre-statehood. Once the water is returned to the stream, just above the city of Spearfish, the flows continue in a northward fashion and are finally used for agricultural pursuits north of Interstate 90.

Whitewood Creek was the second northern Black Hills stream to be sampled in this study. Whitewood Creek is highly influenced by mining and urban development throughout its course. Development of a wastewater treatment plant below the town of Deadwood also has contributed to temperature impacts to the stream.

Few southern Black Hills streams had water in them during the drought. The stream course chosen was Grace Coolidge Creek that flows through Custer State Park. Within Grace Coolidge Creek there are several physical impacts including small dams. Eventually the stream flows out onto the prairie and finally into the Cheyenne River. It was the area of the small dams where temperature data was collected. Many of these areas are heavily used by anglers and the impact to trout survival was in question.

Each of these stream courses provided a good example of the drought impacts on stream fisheries.  A limited number of sensors only allowed for four or five units to be deployed in each stream during the study.  In most cases, sensors were in place from May to October or November.  Whitewood Creek had a longer period as there was a desire to observe winter temperatures in this unique stream.  Water temperature extremes and the daily fluctuations that they experience will be discussed for each stream.

## TEMPERATURE RECORDERS

Temperature recorders designed to capture data for later analysis became available during the mid-1990s.  No longer was there the requirement of single measurements and instruments that tied the scientist’s physical presence to the study area.  The temperature recorders ability to gather data unmanned allowed not only accurate data gathering but also programmed sampling times.  Several designs and accuracy levels are present in these new recorders.  For this study, not only was accuracy of the instrument a concern, but reliability, cost and waterproof were requirements.  Several models fit the requirements in most of these regards; however, the number of instruments needed favored those that were less expensive.  The decision, based after trial runs with different designs and manufactures, was used to use of Onset HOBO ® Water Temp Pro.  This unit allowed for infrared transfer of data, and delayed starting in addition to the above requirements.

## PLACEMENT OF TEMPERATURE RECORDERS

Placement of the units entailed their installation at the tail end of runs and near the center of the thalweg.  These areas have been defined by the USGS as satisfactory for stream situations (USGS variously dated).  The recorders themselves were anchored to the substrate by a length of rebar that was hammered into the streambed.  Attachment to the rebar was achieved by using a welded connector that passed through the end of the temperature probe.

# RESULTS & DISCUSSION

## DETERMINATION OF MAXIMUM TEMPERATURES

Many of the following temperature indices, including maximum temperature, are used in instances as leverage to restrict activities when temperature criteria are exceeded. These limits have been placed and considered necessary by the authors of the Clean Water Act (1977) to protect salmonid fisheries or other designated uses. Several temperature criteria are used across the United States, yet all specify a temperature threshold calculated over a set averaging period. The State of South Dakota utilizes the annual maximum as a water criteria in describing beneficial uses of water.

Annual Maximum

The maximum hourly temperature that a specific water reaches each year is called the annual maximum. The annual maximum has some credibility to its use from a fishery standpoint as it has been used as a “standard” by the state of Washington for salmonid protection (Washington State Department of Ecology 2006). South Dakota uses a somewhat similar approach to the maximum temperature criteria. Specific differences between the annual maximum and South Dakota standards are that the specific temperature is not derived from hourly recordings, but rather is based on two temperatures defining coldwater permanent (18.3$^{o}$C) and coldwater marginal fisheries (23.9$^{o}$C)(see §74:51:01:45 and §74:51:01:46).

Simpson (2006) found that in many cases involving water temperatures in the Black Hills, the state’s water designations were frequently exceeded. The use of a single maximum temperature as a designate for trout survival in the Black Hills does not appear to be appropriate as in many areas wild trout populations exist even with the elevated temperatures. The fact that these limits have been exceeded, under natural conditions, demonstrates the limited application of a single water temperature for the dictates of water quality. Simpson (2006) discussed the potential merits of other measured statistics that may be of more use for the overall discussion of temperature water quality in the Black Hills.

Table 1. Maximum water temperature observed from Grace Coolidge Creek Ponds, Rapid Creek, Spearfish Creek and Whitewood Creek during a period of drought (2005).

| Water Name | Year | Number of Days Counted | MaxOfTemp C |
|---|---|---|---|
| Rapid Creek above Pactola (Silver City) | 2005 | 8352 | 25.4 |
| Rapid Creek at Pactola Basin (Trestle) | 2005 | 8352 | 16.1 |
| Rapid Creek at Thuderhead Falls | 2005 | 8352 | 26.4 |
| Rapid Creek above Cleghorn Hatchery | 2005 | 8352 | 25.7 |
| Rapid Creek below Cleghorn Hatchery | 2005 | 8352 | 18.1 |
| Rapid Creek upper Meadowbrook | 2005 | 8352 | 24.6 |
| Spearfish Creek at pumphouse | 2005 | 8496 | 18.9 |
| Spearfish Creek at small park | 2005 | 8496 | 18.7 |
| Spearfish Creek just below I90 | 2005 | 7321 | 20.9 |
| Spearfish Creek at lowest point on Ramshead | 2005 | 8496 | 22.9 |
| Whitewood Creek above treatment plant | 2005 | 11712 | 23.5 |
| Whitewood Creek below Highway 14A | 2005 | 11712 | 24.2 |
| Whitewood Creek at RedX mine | 2005 | 14881 | 27.4 |
| Whitewood Creek at lowest RedX | 2005 | 11712 | 28.7 |
| Grace Coolidge Creek Pond #1 | 2005 | 8304 | 24.8 |
| Grace Coolidge Creek Pond #2 | 2005 | 8304 | 24.5 |
| Grace Coolidge Creek Pond #3 | 2005 | 8304 | 24.4 |
| Grace Coolidge Creek Pond #4 | 2005 | 8304 | 23.2 |

Each of the four streams exceeded temperature standards of 18.3$^{o}$ and 23.9$^{o}$ C for coldwater permanent and coldwater marginal designations, respectively (see South Dakota Administrative Rules §74:51:01:45 and §74:51:01:46) (Table 1). Applying the state's designation of these two maximum temperature criteria to the field data from Table 1 limits classifiable permanent trout waters to one location (Rapid Creek at Pactola Basin). The application of the state's water temperature designation is limited as there are natural trout populations and hatchery stockings that occur in many of the areas that exceed the yearly maximum temperature.

Warmer waters can be tempered by coldwater additions such as reservoir releases or coldwater springs. The effects of the coldwater release from Pactola Reservoir and the contribution of Cleghorn Springs are seen in the Rapid Creek data (Table 1). In each of these cases, maximum temperatures went from over 25$^{o}$ C to 16.1$^{o}$ C in the case of Pactola basin and to 18.1$^{o}$ C in the case of Cleghorn Springs. Observations also show that these buffers in temperature are only limited in distance as the temperatures increase rapidly by the time the Pactola Basin water reaches Thuderhead Falls. Lower in the watershed, the cooling effect of Cleghorn Springs is limited by the warming effects of Canyon Lake as is shown in the temperature data shown at Meadowbrook Golf Course. Some of this data exhibits temperatures that are now potentially strenuous on trout.

Rapid Creek

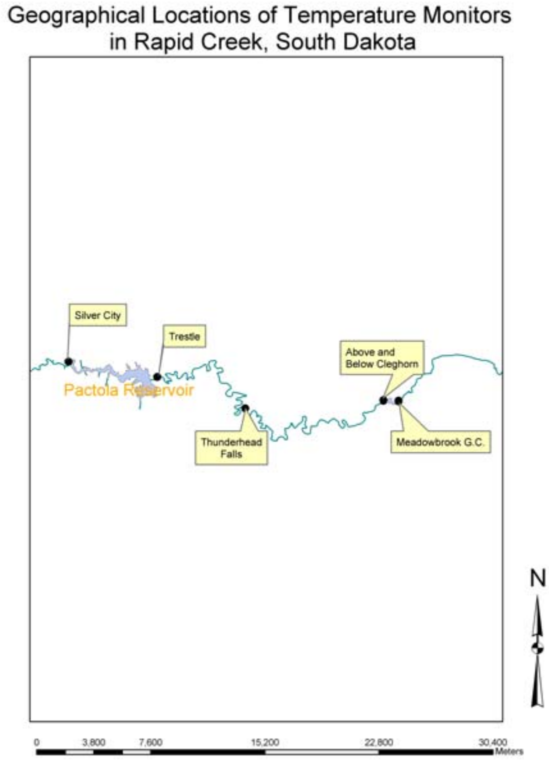


Figure 1. Geographical locations of temperature monitors in Rapid Creek watershed during the study period.

Five separate areas were designated for placement for temperature monitoring in Rapid Creek (Figure 1). Several observations are made from the temperature data based on date. One characteristic determined via temperature loggers was the effect of the coldwater release from Pactola on water temperature. The temperature difference between above reservoir compared to that of Pactola Basin is almost 15$^{o}$ C on some of the hotter days in June (Figure 2). By the end of September the water temperatures above and below the reservoir are essentially equal. The coldwater release also has an impact on water temperature further downstream. Temperature differences from Pactola Basin to Thuderhead Falls were over 10$^{o}$ C at certain times in late May 2005 (Figure 3). These differences dropped to nearly 5$^{o}$ C in early June and remained near this level throughout much of the hotter summer months. The reason for this drop in water temperature, even with the higher air temperatures normally experienced in July and August, is due to the increased releases from Pactola for municipal and agricultural irrigation during this same time. These increased flows represent a greater amount of colder water being transported downstream.

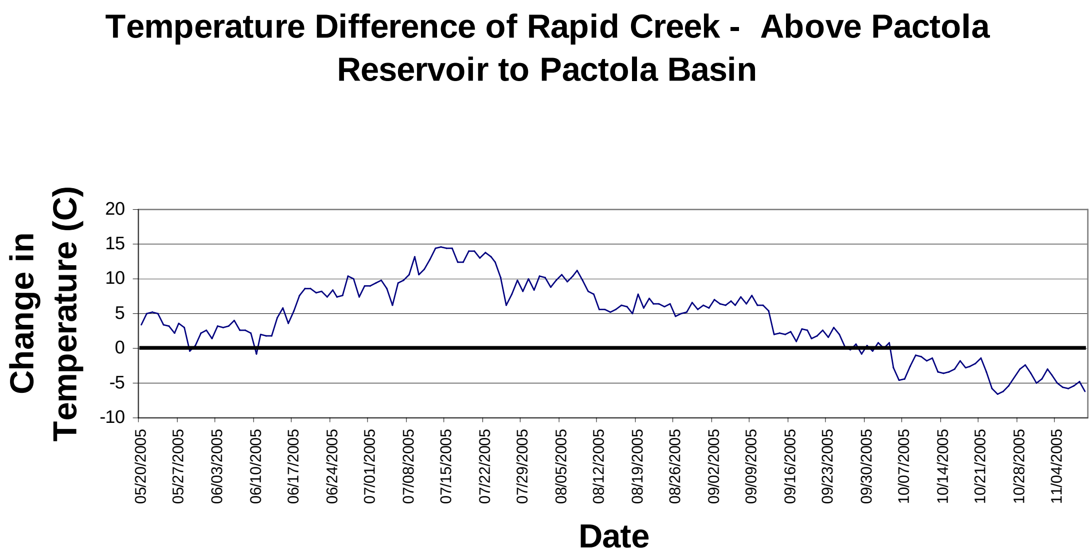


Figure 2. Differences of water temperature determined by remote sensors in Rapid Creek from above Pactola Reservoir compared to lower Pactola Basin, May - November 2005.

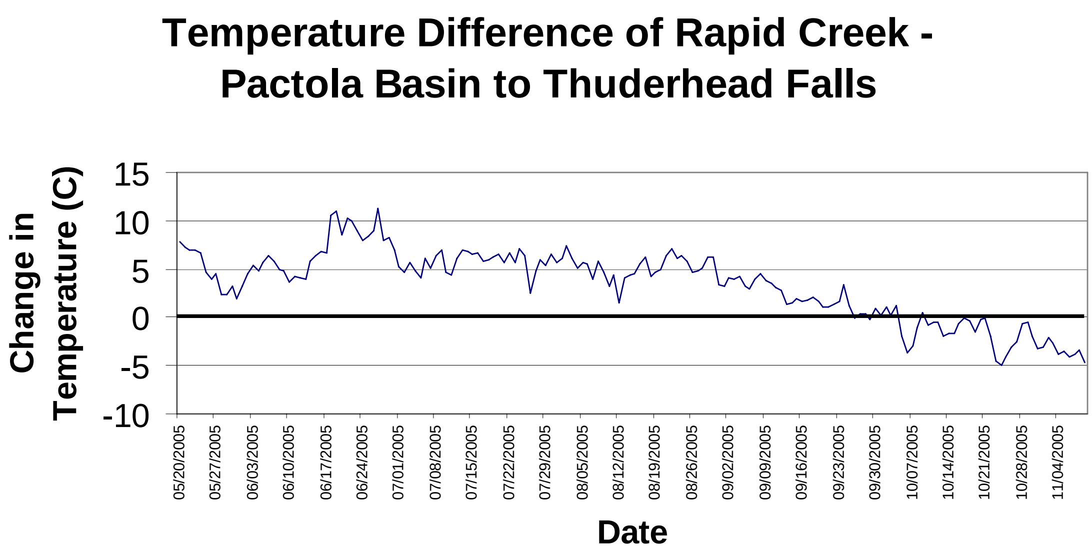


Figure 3. Differences of water temperature determined by remote sensors in Rapid Creek from above Pactola Basin compared to Thuderhead Falls, May - November 2005.

The changes of water temperatures in Rapid Creek are influenced not only by the coldwater releases of Pactola Reservoir but also by springs flowing into the stream as it runs it's course.  In 2005, mid-to-late May air temperatures were extreme and it became evident in the water temperatures measured above Cleghorn Springs hatchery (Figure 4).  The water temperatures, mediated by Cleghorn Springs.  Inflows are less than those of other areas throughout much of the summer.

Below Cleghorn Springs, the water temperature increases in Canyon Lake, before it moves downstream through Rapid City.  Canyon Lake and its warming properties increase the water temperature between 2$^{o}$ and 8$^{o}$ C for much of the summer (Figure 5).  These increases of daily and overall temperature have had an effect on the overall productivity of Rapid Creek.  Electrofishing estimates of adult fish present have traditionally shown that the productivity increases below the reservoir (Figure 6).

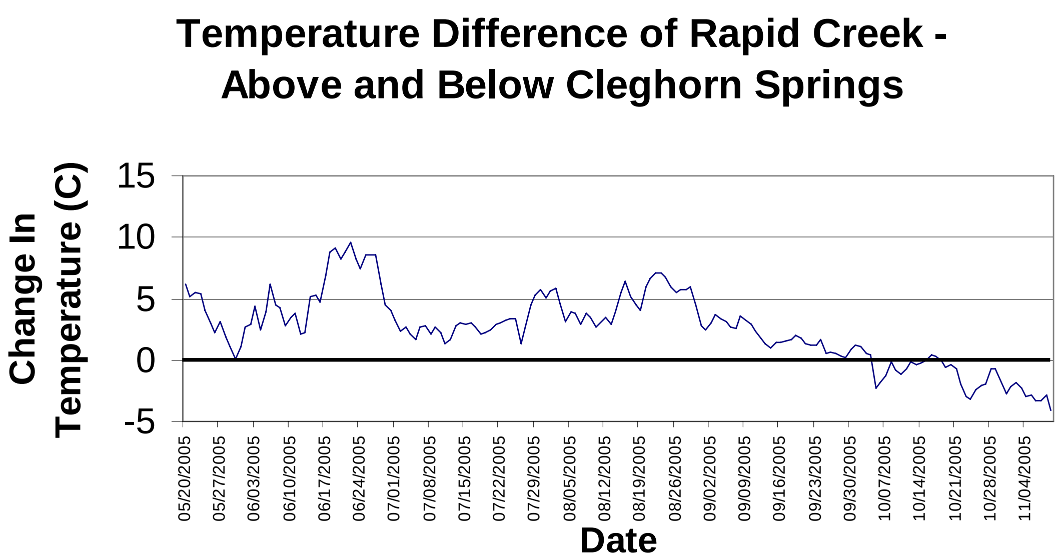


Figure 4.  Differences of water temperature determined by remote sensors in Rapid Creek from above compared to below Cleghorn Hatchery, May - November 2005.

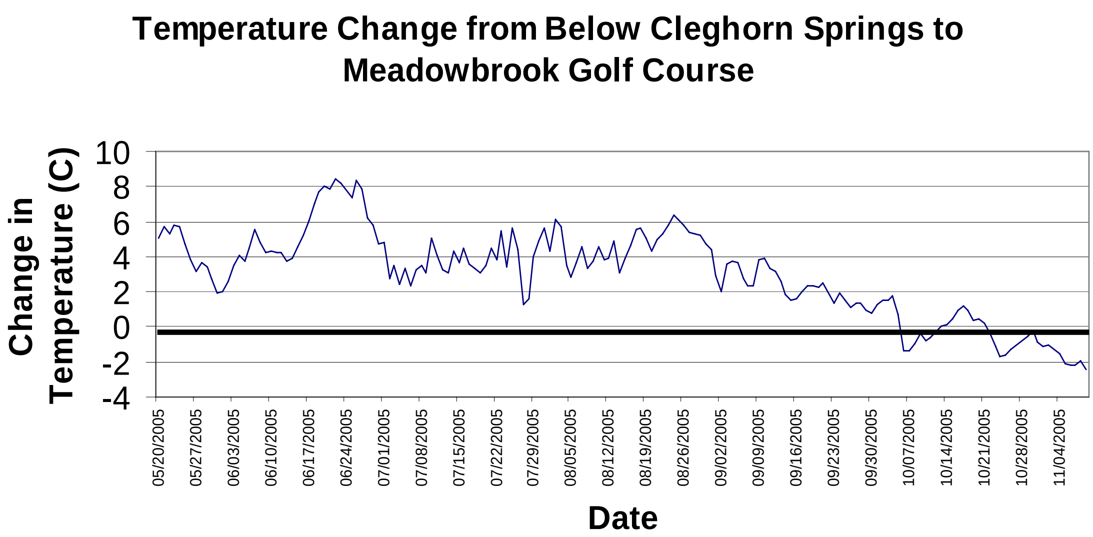


Figure 5. Differences of water temperature determined by remote sensors in Rapid Creek from below Cleghorn Hatchery compared to Meadowbrook Golf Course, May - November 2005.

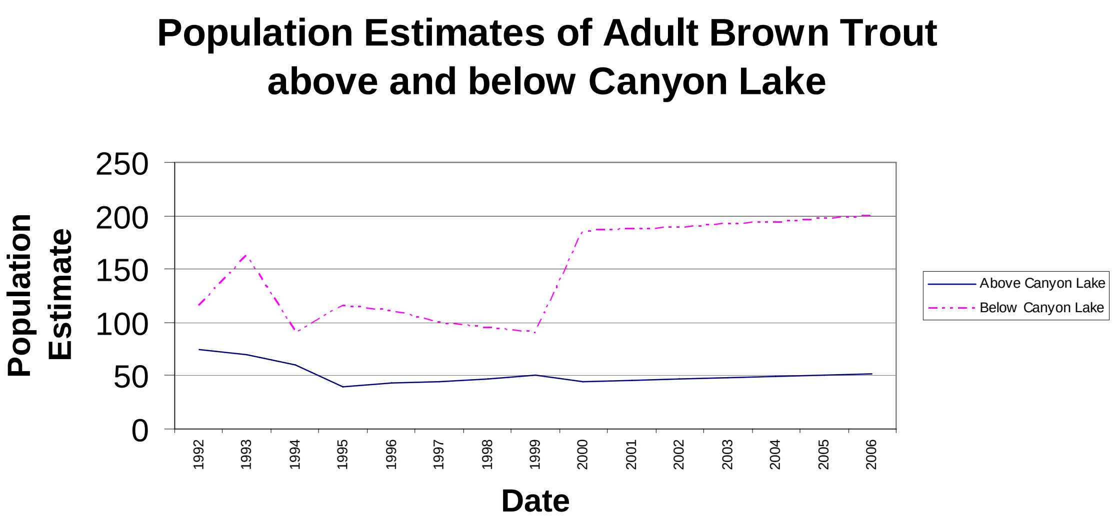


Figure 6. Population estimates of adult brown trout found above and below Canyon Lake.

## Spearfish Creek

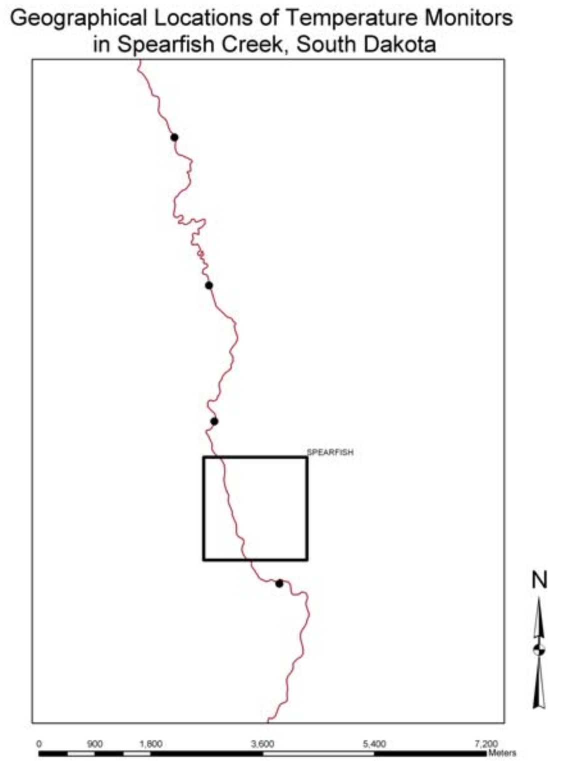


Figure 7. Geographical locations of temperature monitors in Spearfish Creek watershed during the study period.

Four separate areas were designated for placement for temperature monitoring in Spearfish Creek (Figure 7). Spearfish Creek, with the exception of small outtake structures, is a free flowing stream for much of its length. At the area in Spearfish Canyon called Maurice, pumps that move water out for the purpose of electrical generation and other uses remove water from Spearfish Creek. It was below the area where water resumes to the natural creek section that temperatures were taken. Throughout all of the sampled area, temperature increases were in the range of four to five degree Centigrade (Figure 8).

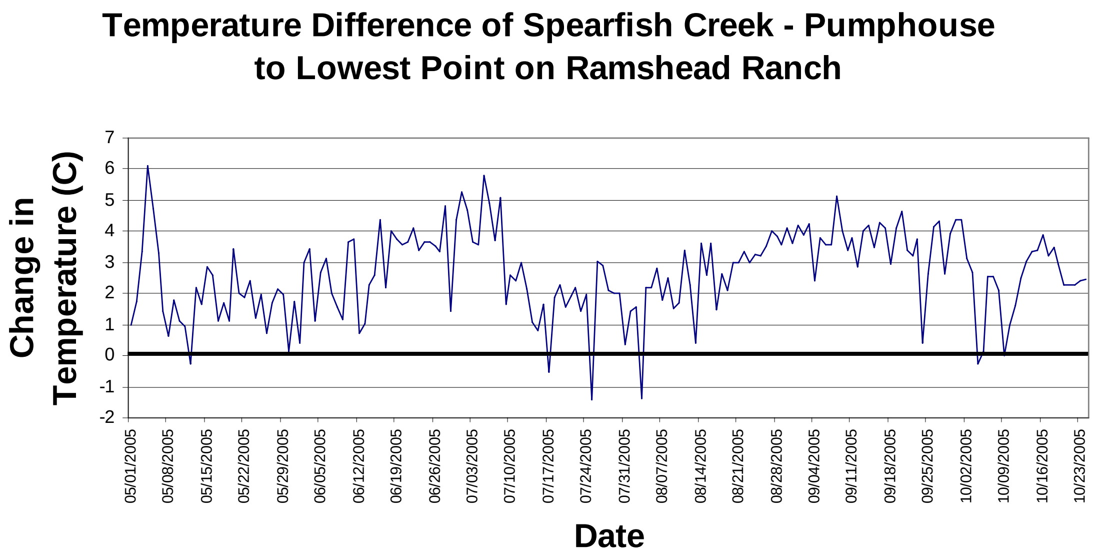


Figure 8. Differences of water temperature determined by remote sensors in Spearfish Creek from Pumphouse compared to lower Ramshead Ranch, May - October 2005.

Whitewood Creek

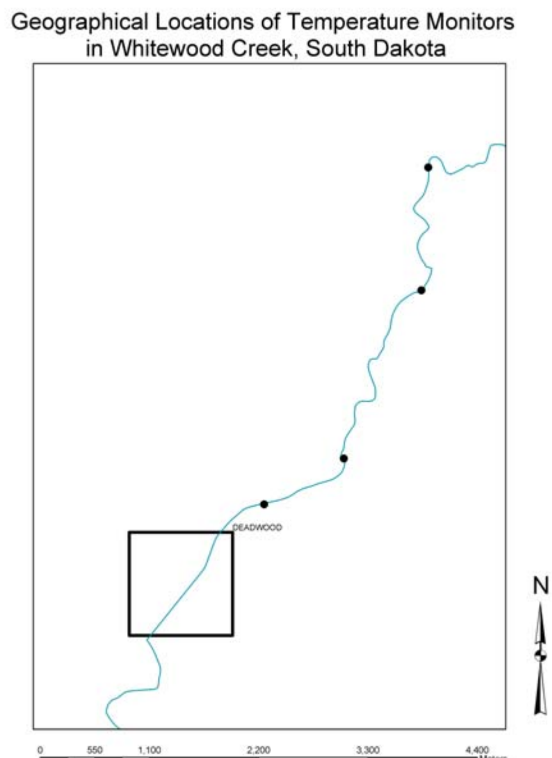


Figure 9. Geographical locations of temperature monitors in Whitewood Creek watershed during the study period.

Four separate areas were designated for placement for temperature monitoring in Whitewood Creek (Figure 9). All sites monitored for temperature in Whitewood Creek are below the town of Deadwood, South Dakota. The major impact that can occur in this area involves the discharge of the town's wastewater after being treated at the wastewater treatment plant. Below state highway 14A, few natural impacts exist (in regards to temperature). The stream flows through many areas where historic mining occurred, including some areas where extensive reclamation has stabilized the shoreline and stream course. Throughout the length of stream that was sampled, a temperature increase of only four degrees Celsius was measured (Figure 10). The impact of the wastewater treatment plant was somewhat limited in regards to temperature shown by limited increases in temperature during the important winter months. These values changed only about four or five degrees Celsius throughout the day (Figure 11). Caution may be advised as too quickly a shift can contribute to mortality factors (Sullivan 2000).

Winter water temperatures taken above and below the effluent were separated out for analysis (Figure 12). Water temperatures in January and February showed a maximum of a five degree Centigrade daily difference in late January. By March, only slight differences in temperature were realized between these two locations.

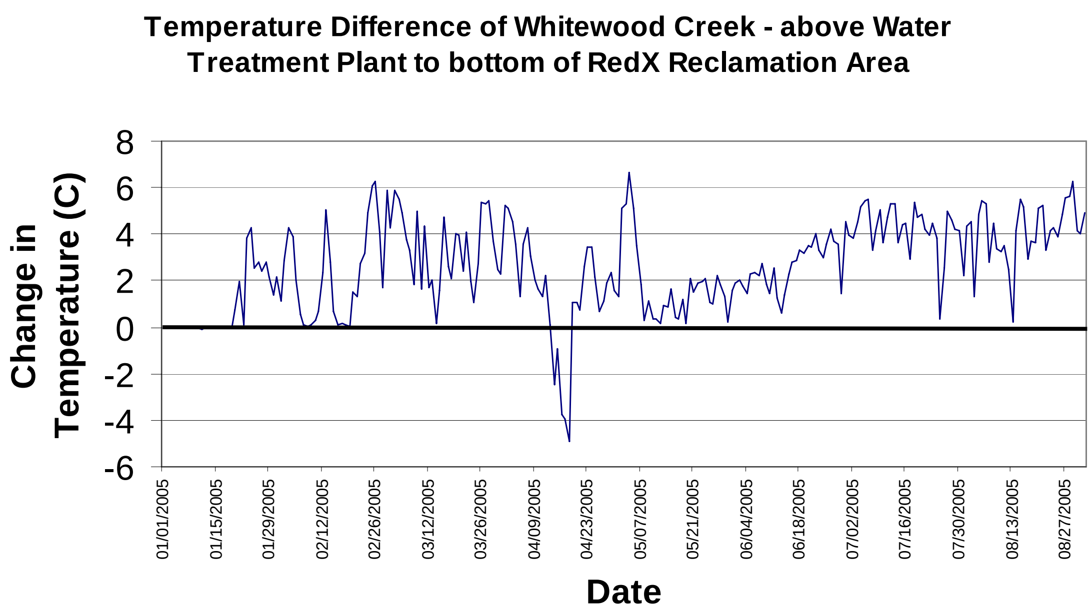


Figure 10. Differences of water temperature determined by remote sensors in Whitewood Creek from above Water Treatment Plant compared to bottom of RedX Reclamation Area, January - August 2005.

Temperature Difference of Whitewood Creek - Above and Below Water Treatment Plant

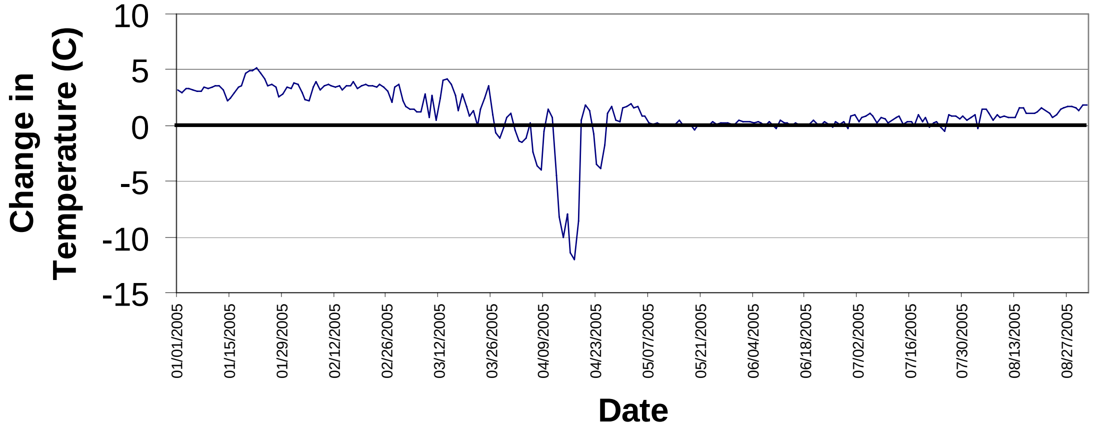


Figure 11. Differences of water temperature determined by remote sensors in Whitewood Creek from above Water Treatment Plant compared to below Water Treatment Plant, January - August 2005.

**Whitewood Creek Water Temperature**

**above and below water treatment plant**

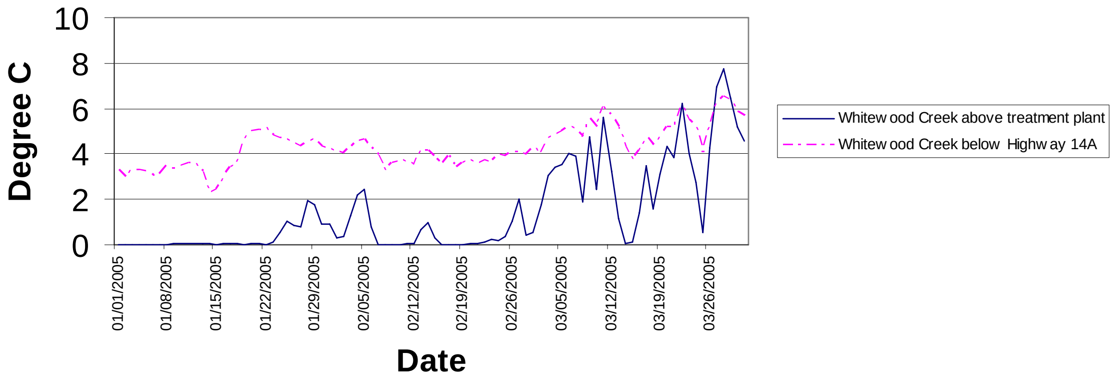


Figure 12. Whitewood Creek water temperatures taken above and below the wastewater treatment plant during the winter of 2005.

## Grace Coolidge Walk-in Ponds

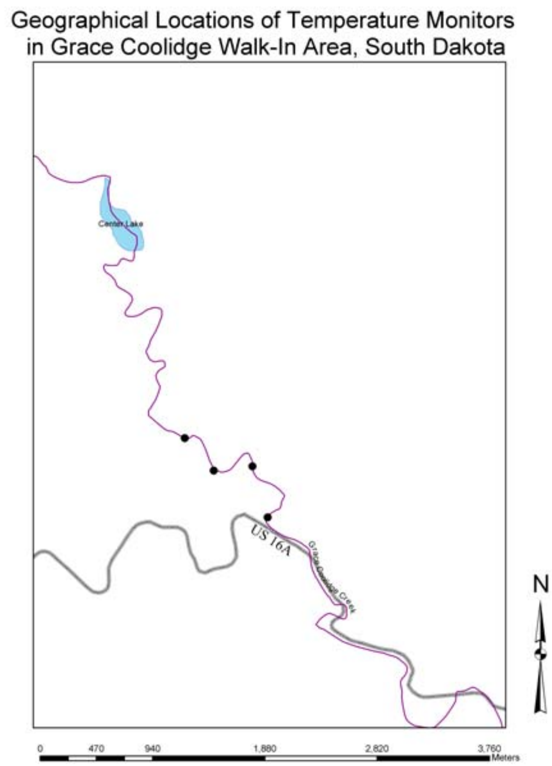


Figure 13. Geographical locations of temperature monitors in Grace Coolidge Creek watershed during the study period.

Four separate ponds were designated for placement of temperature monitoring in Grace Coolidge Creek (Figure 13). Grace Coolidge Creek flows through Center Lake and into the series of small ponds called Grace Coolidge Ponds. After leaving Center Lake, the stream flows through a series of seven small dams that are used by the public for a variety of purposes, including fishing. The water temperature did not change much throughout the sampled area in Grace Coolidge Creek (Figure 14). The stream course areas may also be influenced by springs, as temperatures and flow continued in this area, despite other nearby streams becoming dry in 2005 and later. The highest temperature difference between the top and bottom pond was measured in early June. Human interference may have influenced some of the outlying temperatures, as there was considerable tampering with collecting units by the public.

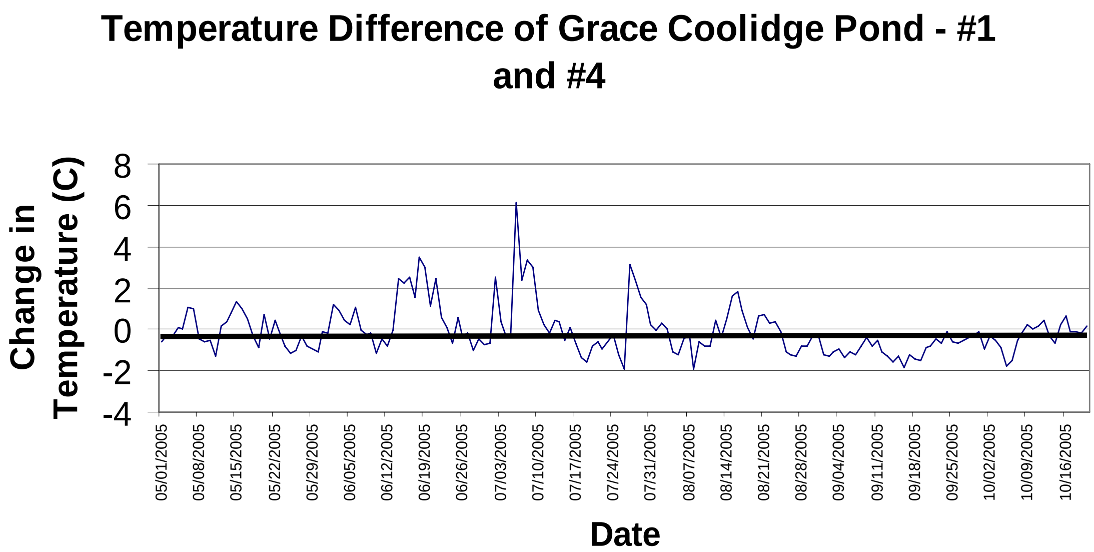


Figure 14. Differences of water temperature determined by remote sensors in Grace Coolidge Creek from Pond #1 compared to Pond #4, May - October 2005.

Drought impacts on the fisheries of the Black Hills streams are poorly documented. This study was a first attempt to quantify what conditions trout have to contend with during the summer. Effects of temperature buffering were observed in two cases: coldwater releases from a reservoir and coldwater springs. The streams selected were based on their known ability to hold trout during drought conditions. All waters sampled experienced water temperatures above the state's designation for permanent and marginal designated uses. The maximum temperature designation used by South Dakota has limited application for protecting coldwater fisheries in the case of drought conditions, because our ability to modify the situation is extremely limited.

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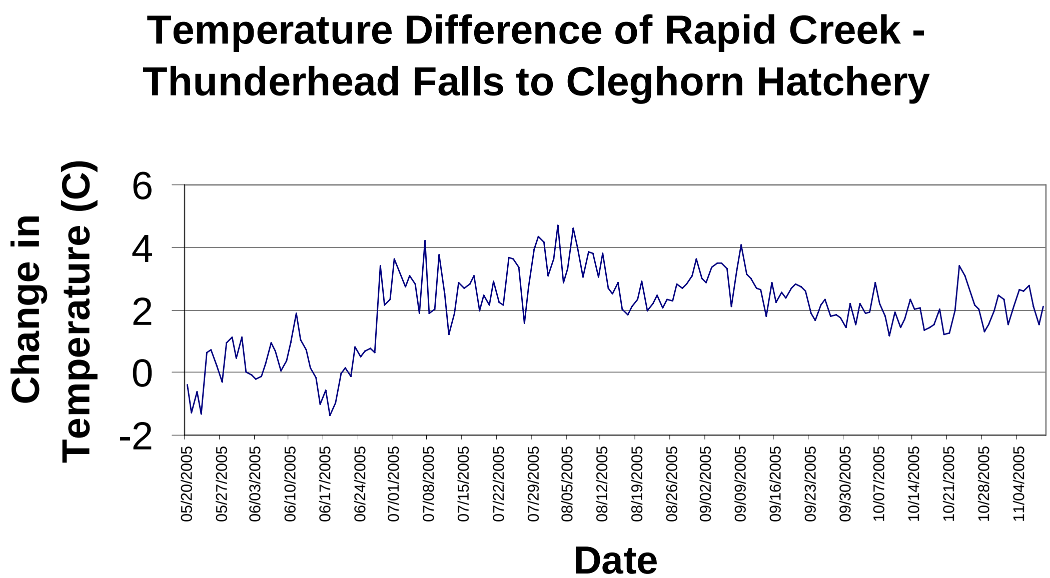
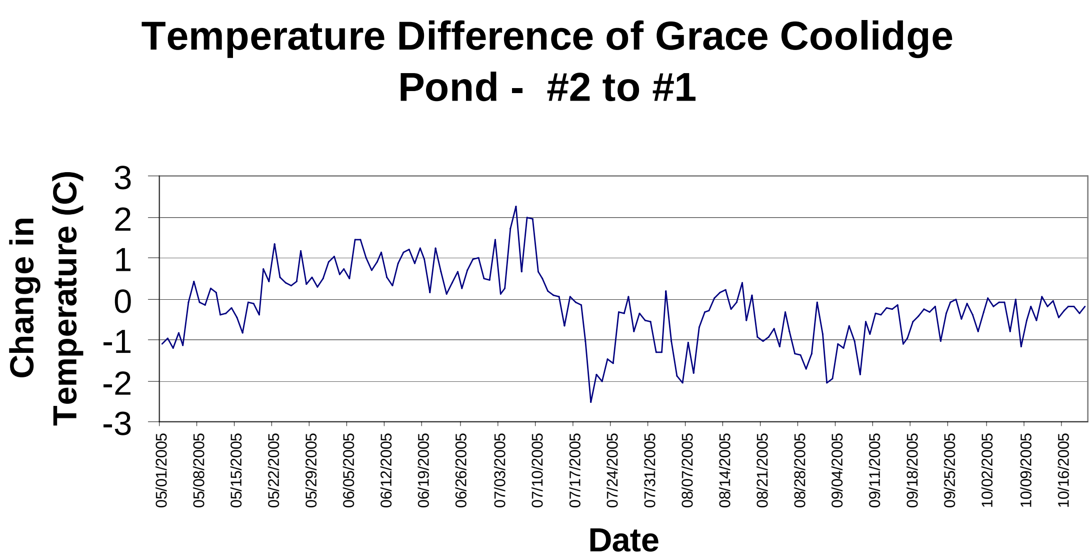
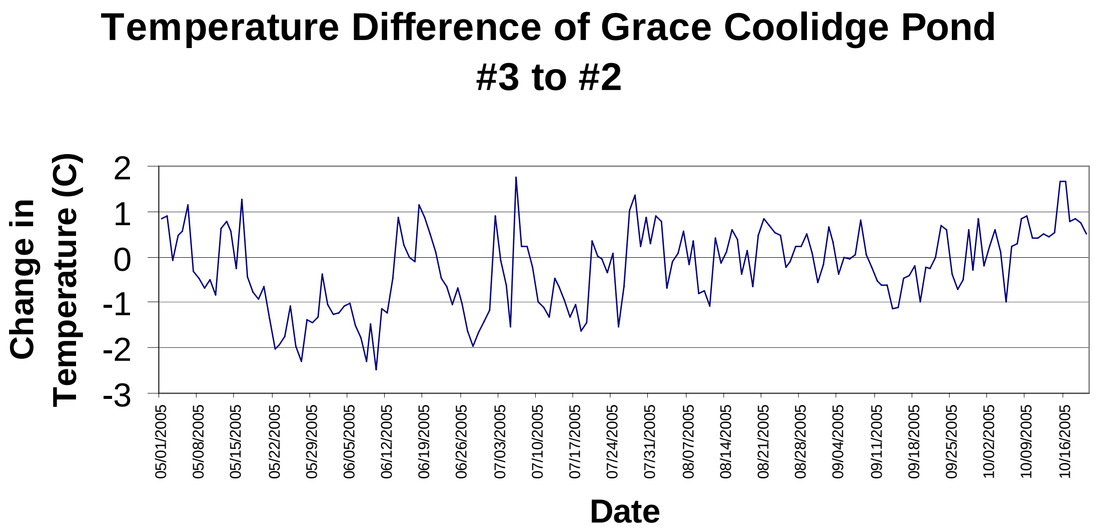


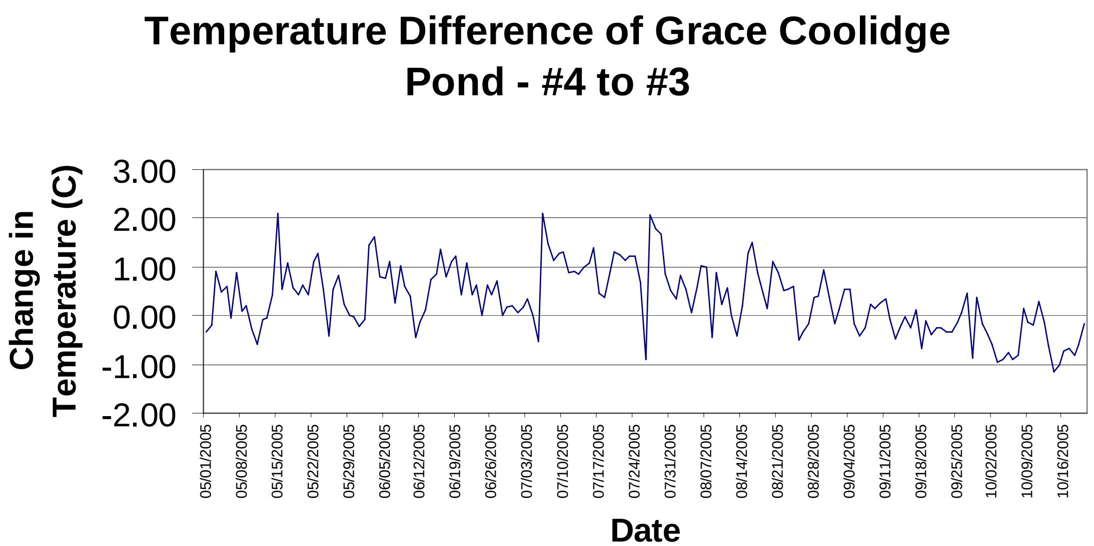

Appendix Figure 1. Differences of water temperature determined by remote sensors in Rapid Creek from above Thunderhead Falls to Cleghorn Hatchery, May - November 2005.




Appendix Figure 2. Differences of water temperature determined by remote sensors in Grace Coolidge Creek from Pond #2 to Pond #1, May - October 2005.




Appendix Figure 3. Differences of water temperature determined by remote sensors in Grace Coolidge Creek from Pond #3 to Pond #2, May - October 2005.




Appendix Figure 4. Differences of water temperature determined by remote sensors in Grace Coolidge Creek from Pond #4 to Pond #3, May - October 2005.